Final Background Document
on the sector

Off Road
Maritime activities : Ships

Prepared by CITEPA, Paris

Summary

Data currently used in RAINS are displayed in this paragraph.

Seven reference engines are defined according to their size.

Table 5.3.1 summarizes the emission factors with the corresponding abatement efficiencies for each measures.
Table 5.3.2 summarizes investments and operating costs for each measure.

Table 6.2.1 : Fuel parameters : these data have just to be entered in the tool once.

Table 6.2.2 : Fuel prices (net of taxes)

Table 6.2.3 : Activity levels : Marine fuel and diesel consumptions

Total activity (t fuel consumed / y) in 2000 to 2020.

Pollutant's emissions are assessed by the fuel consumption method.

Table 6.2.4 : Distribution of the different engine sizes (% of total activity (fuel use))

Tables 6.2.5 : Data necessary to estimate the number of engines
Table 6.2.6 : Fuel efficiency improvements compared to the base year 2000
Table 6.2.7 : Change in activity per engine relative to the base year 2000
Table 6.2.8 : Application rate and Applicability for each combination of measure

Cost data are derived from reference [1].

Maritime activities : ships

SNAP 080402 National sea traffic within EMEP area or NFR 1A3dii National Navigation, **SNAP 080404** International sea traffic (international bunkers) or NFR 1A3di International Navigation, **SNAP 080403** National fishing (mobile motors and machines) or NFR 1A4ciii National Fishing.

GRT : used to describe merchant ships, especially passenger-carrying ships, refers to the *volume* of space within the hull and enclosed spaces above the deck which is available for cargo, stores, fuel, passengers and crew. GRT is measured in units of 100 cubic feet.

ACTIVITY : fuel consumption (GJ/year)
POLLUTANTS CONSIDERED : NOx, and SO_2

1 Data currently used in the RAINS model

Following data are just displayed for comparison reasons.

Data are derived from reference [10].

- Activity

Activity used in the current stage of development of the RAINS model is the fuel used (expressed in PJ of fuel consumed).

- Emission factors

Table 1.1 : Emission factors used in the RAINS PM module for maritime activities

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]	TSP [g/kWh] *
Medium vessels	25,7	27,2	28,6	0,26
Large vessels	25,7	27,2	28,6	0,26

* Coefficient expressed in g/kWh was calculated from the coefficient in g/GJ assuming 40% efficiency of diesel engine.

- Engines considered

Table 1.2 : Sector considered in RAINS

Abbreviations used in RAINS	Sector
TRA_OT_M	Medium vessels
TRA_OT_L	Large vessels

➢ Techniques and associated costs

Table 1.3 : Removal efficiencies and cost parameters for control technologies used in maritime activities

Technology	Removal efficiency [%]	Unit investment [€/vehicle]	Fixed O+M [%]
Combustion modification, medium vessels	20	219 522	2,0
Combustion modification, large vessels – fuel oil	40	439 043	2,0
Combustion modification, large vessels – diesel	20	371 250	2,0

2 Short technology description

Only the largest engines (> 30 liters/cylinder) used primarily for propulsion in ocean-going ships are studied hereafter.

Study [1] gives information at a European level. 2001 is taken as baseline and has been modelled based on the 1996 situation with a projected 1,6% fuel consumption increase.
Air pollutant from ocean-going ships do not stop at national boundaries. Some of them disperse to the land especially costal areas.

SO_2 and NOx emissions are particularly significant, causing acidification and eutrophisation and leading to the formation of ground-level ozone and particulate matter [2].

2.1 Fuel consumption

33,5 Mt of **bunker fuels** are consumed in European marine areas.

2.2 Number of ships

Approximately 30 000 ships over 250 GRT are operating in European waters.

2.3 NOx, SO_2, VOC and PM emissions

- 2,3 Mt of NOx are released by ships in the European marine area.
- Projections suggest that SO_2 emissions of ship might reach three quarters of land emissions by 2010 [2].
- VOC emissions are considered for ship-loading of gasoline : this task is covered in the refinery sector; however, VOC emissions are low (0,07% of total emissions in the EU).

Only NOx and SO_2 emissions are considered in this report.

3 EU regulation

3.1 International regulation

Mandatory controls on the exhaust emissions from marine sources have historically been of very limited extent. Situation has changed with the adoption of Annex VI “Regulation for the Prevention of Air Pollution from Ships” of the MARPOL 73/78 Convention [3].

NOx emissions : all diesel engines over 130 kW either installed on ships built on or after 1st January 2000 or those which are subject to major conversions must have a cycle weighted emission value within the limits of the IMO curve : this curve shows NOx emission limits (g/kWh) versus engine rated speed (rpm) [4]. To simplify, IMO limit curve levels are 17 g/kWh at slow speed, 12 g/kWh at medium speed and 9,8 g/kWh at high speed.

IMO limit levels are modest reductions relative to the previous situation [1].

SO_2 emissions : high SO_2 emissions from ships are caused by extremely high sulphur content in marine fuels, which may reach 4-5% and more. MARPOL Annex VI establishes a global cap of 4,5% for heavy fuel oil burned by ships and designates two Sulphur Emissions Control Areas (the North Sea & English Channel, and the Baltic Sea) where fuel burned by ships must be below 1,5% sulphur [2].

3.2 European regulation

The European Commission is willing to regulate pollutant emissions from sea-going boats. The Commission's first priority is to reduce SO_2 and PM emissions [5]. Currently, marine fuel has an average sulphur content of 2,7%.
To reduce ship's NOx emissions, the strategy proposes that the Commission should work with Member States to press for tougher engine standards through the International Maritime Organisation. This approach will reduce NOx emissions from all the ships entering EU seas not just those flagged in the European Union. In parallel the Commission aims to develop market-based instruments to encourage ship owners to use NOx reduction technologies in EU seas.

A proposition of Directive to amend Directive 1999/32/EC [6] relating to a reduction in the sulphur content of certain liquid fuels was elaborated by the Commission [7].

Aims of the proposition :
- Introduce a 1,5% sulphur limit for marine fuels used by all ocean-going vessels in the North Sea, English Channel and Baltic Sea, in line with MARPOL Annex VI requirements,
- Introduce a 1,5% sulphur limit for fuels used by passenger vessels on regular services to or from any Community port,
- Amend existing sulphur provisions for marine gas oils used by ocean-going and inland vessels : sulphur content of marine fuels used by ships on inland waterways and at berth in Community ports should be limited to 0,2% sulphur (0,1% by 2008).

4 Definition of Reference Ships

The following data are reported from reference [1]. Assuming that the average NOx emission rate is **13,5 g/kWh** in European waters and knowing the annual MWh per category, NOx emissions per ship can be determined.
According to [8], engines not equipped with exhaust-gas treatment techniques emit between 60 and 90 g of NOx / kg of fuel burned corresponding to 12 to 18 g/kWh.
Average MWh are given for **European waters only**.

Table 4.1 : Reference ships

Reference engine codes (REC)	Reference ship	Rated power [MW]	Avg. MWh/y	NOx emissions [t/y]
01	Tanker > 1000 GRT ; av.27 kGRT	11,9	6 795,8	91,7
02	Dry bulk > 1000 GRT ; av. 27 kGRT	12,3	6 985,2	94,3
03	Container > 1000 GRT ; av. 22 kGRT	21,5	17 316	233,7
04	Ro-Ro > 1000 GRT , av. 18 kGRT	22,9	63 891	862,5
05	Cruise / Passenger > 1000 GRT ; av. 23 kGRT	32,0	35 826,3	483,6
06	Other Cargo > 1000 GRT ; av. 5,7 kGRT	8,4	5 869,8	79,2
07	All ships between 250 and 1000 GRT; av. 670 GRT	0,5	1 115,6	15
	Total			2 300

5 Emission abatement techniques and costs

5.1 Primary measures (NOx abatement techniques only)

Several primary measures are mentioned in [1] :

Table 5.1.1 : Primary measures

Primary measure codes (PMC)	Description	Abatement efficiency [%] on NOx emissions
00	None	0
01	Water injection or humidification	30-50
02	Firing pressure influence	?
03	Exhaust gas recirculation (EGR)	?
04	Fuel nozzle adaptation / fuel injection	20
05	Fuel – water emulsification	Depends on the water ratio
06	Humid air motor	Up to 70

- Firing pressure influence : injection retardation which lowers peak temperatures.
- EGR : changes the ratio of oxygen to nitrogen within air entering into the engine.
- Fuel nozzle adaptation : can influence NOx emissions.
- Fuel-water emulsification : typically, for every one percent of water that is added, NOx emissions are reduced by 50%.
- Water Injection or humidification : addition of water in the combustion chamber through separate nozzles. This technique lowers combustion peak temperature so NOx emissions are reduced.
  Water Injection is capable of reducing NOx emissions to 7 g/kWh.

5.2 Secondary measures

5.2.1 Selective Catalytic Reduction (SCR)

SCR systems can be used to treat the exhaust gas. A small amount of a urea/water solution is injected into hot exhaust gas, where it is vaporised and mixes with NOx. The urea injection rate may be adjusted anywhere from 0% to 100%, leading to corresponding levels of NOx reduction, up to 99% [1].

Table 5.2.1 : Secondary measures

Secondary measure code (SMC)	Description	Abatement efficiency [%]
00	None	0
01	SCR	Up to 90 on NOx [11]

For SCR, abatement efficiency depends on the urea/water mixture concentration injected into the exhaust gas. NOx emissions of 2 g/kWh can be obtained.

5.3 Emission factors and costs data for the different combinations

Only average emission factors for all types of vessels are defined in table 5.3.1.

Table 5.3.1 : Emission factors (EF) for each combination of measures

PMC SMC	EF NOx (g/kWh)	Q	CI %
00 00	13,5	4	30
01 00	7	4	30
00 01	2	4	30

Q : Quality of data
CI : Coefficient of variation

Table 5.3.2 : Investments and operating costs

Combinaison Code REC PMC SMC	Investments (€$_{2000}$)	Q	CI %	Operating costs (€$_{2000}$/y)	Q	CI %
01 00 00	0	-	30	0	-	30
01 01 00	108 225	3	30	26 745	3	30
01 00 01	710 605	3	30	93 605	3	30
02 00 00	0	-	30	0	-	30
02 01 00	108 225	3	30	27 490	3	30
02 00 01	730 415	3	30	96 215	3	30
03 00 00	0	-	30	0	-	30
03 01 00	108 225	3	30	68 145	3	30
03 00 01	1 278 105	3	30	238 510	3	30
04 00 00	0	-	30	0	-	30
04 01 00	108 225	3	30	76 830	3	30
04 00 01	1 360 900	3	30	268 900	3	30
05 00 00	0	-	30	0	-	30
05 01 00	108 225	3	30	96 935	3	30
05 00 01	1 904 040	3	30	339 265	3	30
06 00 00	0	-	30	0	-	30
06 01 00	108 225	3	30	25 410	3	30
06 00 01	499 135	3	30	88 935	3	30
07 00 00	0	-	30	0	-	30
07 01 00	29 760	3	30	1 420	3	30
07 00 01	29 760	3	30	4 970	3	30

6 Data to be provided by national experts for the completion of the database for their own country

The following tasks are required :

Validation work

For representing costs in this sector, the national expert is invited to comment the methodology defined by the Secretariat.

- Validate of investment costs provided or,
- Provide other costs for the same abatement techniques and justify them.

Comments have to be sent to the Secretariat in the two weeks after electronic publication of the document.

Provision of specific data

Tables to be filled in by national experts

- Fuel parameters

All fuel parameters have to be filled in only once in the tool in the table "Fuel characteristics".

Table 6.2.1 : Fuel parameters

	2000	2005	2008	2010	2015	2020
Sulphur content of marine fuels (%)						
Heat value of marine fuels [GJ/t]						
Sulphur content of gas-oil (%)						
Heat value of gas-oil [GJ/t]						

Table 6.2.2 : Fuel prices (net of taxes)

	2000	2005	2008	2010	2015	2020
Marine fuels price (€$_{2000}$/l)						
Gas-oil price (€$_{2000}$/l)						

- Activity level

IIASA uses international fuel statistics to define fuel consumption in each country.

Although IIASA tries to derive fuel consumption in each sub-sector from international energy statistics and available energy projections, a high uncertainty still exists. Thus the experts are requested to give the total fuel use for the base year (2000) and a national projection up to 2020 in 5-years intervals.

Table 6.2.3 : Fuels consumption (GJ / y)

Activity	2000	CI%	2005	CI%	2010	CI%	2015	CI%	2020	CI%
Marine fuel [GJ]										
Gas oil [GJ]										
Default values proposed for CI		10		20		50		100		100

For explanations on the coefficient of variation (CI), please refer to the document Methodology.

- Emissions

National experts do not need to calculate the emissions for individual engine/vehicle categories. The calculations will be done by the RAINS model. However, experts are requested to provide country-specific data for calculations. Below the formulas used and the appropriate coefficients are presented.

Annual SO_2 emissions can be calculated as follows :

$$\textbf{Emissions [t/y]} = 2 \times \textbf{Fuel Consumption (t/y)} \times \textbf{S content (\%)} / 100$$

For other pollutants, two methods can be used to estimate emissions from non road engines :

- Annual emissions per engine of NOx can be calculated with the following equation :

$$\textbf{E [t/y]=Load Factor} \times \textbf{Power [kW]} \times \textbf{Annual use [h/y]} \times \textbf{Emission Factor [g/kWh]} / 10^6$$

Country specific data (engine characteristics) are required for each type of engines :
- Load factor (<1 : gives the average power delivered by the engine),
- Annual use (h/y),
- Operating lifetime (year),

- Consumption method : emission factors are expressed in g of pollutant / GJ using the engine's efficiency.

According to IIASA [10], engine's efficiency is considered to be about 40% for diesel engines. Currently, no better data have been provided.

$$\textbf{E [t/y]= Fuel consumption [GJ/y]} \times \textbf{Emission Factor [g/GJ]} / 10^6$$

This method is used in the RAINS model.

The following data are required :

- Distribution of engine's sizes

- Distribution of power ranges (% of total activity (fuel use)) has to be determined for the base year 2000 and projection years 2005, 2010, 2015, 2020.

Table 6.2.4 : Distribution of the different engine sizes (% of total activity (fuel use))

REC	Proportion [%] in 2000	Proportion [%] in 2005	Proportion [%] in 2010	Proportion [%] in 2015	Proportion [%] in 2020
01					
02					
03					
04					
05					
06					
07					
Total	**100**	**100**	**100**	**100**	**100**

➢ Number of engines

For cost calculations, number of engines in the base year (2000) is necessary. If this information is available, this should be specified in column 2 of table 6.2.5. Alternatively, data about load factor and annual engine use (columns 3 and 4) should be estimated. In both cases a typical operating lifetime of each engine category (column 5) should be given.

Table 6.2.5 : Engine characteristics in the base year 2000

To be completed	Either 2	Or 3 and 4		And 5
Type of engine REC	**Total number of engines**	**Load factor**	**Annual use (h/y)**	**Operating lifetime (years)**
01				
02				
03				
04				
05				
06				
07				

➢ Other parameters

Engine characteristics given in Table 6.2.5 are valid for the base year 2000. For other years, two additional parameters should be specified :

- fuel efficiency improvement (Table 6.2.6),
- change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 6.2.7).

If country specific data are not available, default values already included in the following tables will be used .

Table 6.2.6 : Fuel efficiency improvement for individual engine sizes relative to the base year (Fuel consumption per unit of output in year 2000 = 100 %)

REC	**2000**	**2005**	**2005**	**2010**	**2010**	**2015**	**2015**	**2020**	**2020**
01	100	98		96		94		92	
02	100	98		96		94		92	
03	100	98		96		94		92	
04	100	98		96		94		92	
05	100	98		96		94		92	
06	100	98		96		94		92	
07	100	98		96		94		92	

Table 6.2.7 : Change in activity per engine relative to the base year <u>for agriculture and forestry</u> (Activity per engine in year 2000 = 100 %)

REC	**2000**	**2005**	**2005**	**2010**	**2010**	**2015**	**2015**	**2020**	**2020**
01	100	100		100		100		100	
02	100	100		100		100		100	
03	100	100		100		100		100	
04	100	100		100		100		100	
05	100	100		100		100		100	
06	100	100		100		100		100	
07	100	100		100		100		100	

➢ Application rate and applicability

IIASA experts assume a certain lifetime of engines and from this they calculate what proportion of total fuel use will be by vehicles purchased after the date of enforcing of a certain regulation.
Since national experts may have more detailed data, it is worth to ask them about application rates and applicability factors.

Table 6.2.8 : Application rate and Applicability (% of total activity (fuel use))

REC PMC SMC	Application rate in 2000 [%]	Application rate in 2005 [%]	Appl. [%]	Application rate in 2010 [%]	Appl. [%]	Application rate in 2015 [%]	Appl. [%]	Application rate in 2020 [%]	Appl. [%]
01 00 00									
01 00 01									
01 01 00									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00 00									
02 01 00									
02 00 01									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00 01									
03 01 00									
03 00 01									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00 00									
04 01 00									
04 00 01									
Total REC 04	**100**	**100**		**100**		**100**		**100**	
05 00 00									
05 01 00									
05 00 01									
Total REC 05	**100**	**100**		**100**		**100**		**100**	
06 00 00									
06 01 00									
06 00 02									
Total REC 06	**100**	**100**		**100**		**100**		**100**	
07 00 00									
07 01 00									
07 00 01									
Total REC 07	**100**	**100**		**100**		**100**		**100**	

7 Explanatory notes

7.1 Emission factors

According to [1], the average NOx emission rate is **13,5 g/kWh** in European waters. This value is used in this report.

7.2 Derivation of Cost Data

7.2.1 Investment costs

Only the two more widely used techniques have been studied in [1].

- Water Injection (WI) system

For this system, capital cost does not depend on the ship type or on the rated power of the vessel. It has been considered that a cost of 108 225€ can be attributed to all ships except small ones for which a cost of 29 760 € should be incurred.

- SCR system

For this system, investment is directly proportional to the rated power : the ratio is about 55 000 €/MW.

Table 7.2.1.1 : Investment costs

REC	Investment for WI [$€_{2000}$]	Q	CI %	Investment for SCR [$€_{2000}$]	Q	CI %
01	108 225	3	30	710 605	3	30
02	108 225	3	30	730 415	3	30
03	108 225	3	30	1 278 105	3	30
04	108 225	3	30	1 360 900	3	30
05	108 225	3	30	1 904 040	3	30
06	108 225	3	30	499 135	3	30
07	29 760	3	30	29 760	3	30

7.2.2 Operating costs

- WI system

A figure of 1,1 €/MWh is used.

- SCR system

Operating costs represent 3,80 €/MWh.

Operating costs are given for the total average annual MWh per ship and per year.

- PM filter system [10]

Costs will be incurred for regeneration purposes, maintenance costs (ash cleaning) as well as replacement requirements.

Table 7.2.2.1 : WI and SCR operating Costs [1]

REC	Annual MWh	Operating costs for WI [$€_{2000}$]	Operating costs for SCR [$€_{2000}$]	Q	CI %
01	24 712	26 745	93 605	3	30
02	25 401	27 490	96 215	3	30
03	62 967	68 145	238 510	3	30
04	70 990	76 830	268 900	3	30
05	89 566	96 935	339 265	3	30
06	23 479	25 410	88 935	3	30
07	1 313	1 420	4 970	3	30

- Fuel consumption variations

The application of certain technologies leads to fuel consumption variations.

Table 7.2.2.2 : Average fuel consumption variation [%] compared to PMC/SMC 0000

PMC SMC	Fuel variation (%)
00 00	0
01 00	NA
00 01	NA

NA : Non Available

Fuel consumption variations are not assessed in this document because of a lack of information.

- Sulphur content of fuels

According to [7], the following costs will be incurred to reduce sulphur content of fuels :

Table 7.2.2.3 : Average incremental costs (€/tonne)

Explanations	Incremental cost (€/tonne)
Use of 1,5% sulphur marine fuel (instead of heavy fuel oil) for use in North Sea & Baltic Sea and for use by passenger vessels on regular services	50
Use of 0,2% sulphur marine fuel (instead of heavy fuel oil) for use in EU sea ports (0.1% from 2008)	100
Use of 0,2% sulphur marine fuel (instead of marine distillate oil at 1,5%) for use in EU sea ports (0.1% from 2008)	15,5

8 References

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